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National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers

Guidance for Calculating Emission Credits Resulting from Implementation of Energy Conservation Measures

July 2012

Prepared by

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UT-BATTELLE

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Energy and Transportation Science Division

NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR MAJOR SOURCES: INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL BOILERS

GUIDANCE FOR CALCULATING EMISSION CREDITS RESULTING FROM IMPLEMENTATION OF ENERGY CONSERVATION MEASURES

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1. INTRODUCTION

The purpose of this document is to provide guidance for developing a consistent approach to documenting efficiency credits generated from energy conservation measures in the Implementation Plan for boilers covered by the Boiler MACT rule (i.e., Subpart DDDDD of CFR Part 63).

This document divides boiler system conservation opportunities into four functional areas: 1) the boiler itself, 2) the condensate recovery system, 3) the distribution system, and 4) the end uses of the steam (Fig. 1). This document provides technical information for documenting emissions credits proposed in the Implementation Plan for functional areas 2) though 4). This document does not include efficiency improvements related to boiler tune-ups. Information regarding boiler tune-ups can be found in the Boiler Tune-up Guide.

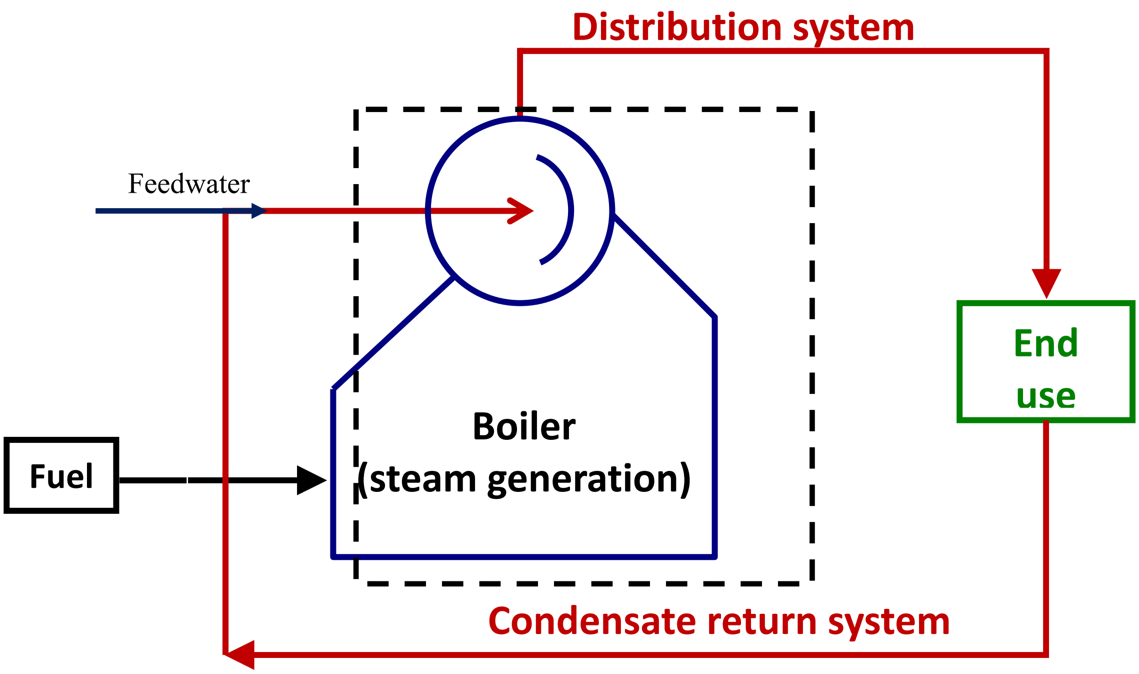

Fig. 1. Boiler system functional areas.

2. COMPLIANCE REQUIREMENTS

If a site elects to comply with the alternative equivalent steam output-based emission limits, instead of the heat input-based limits in Table 2 of Subpart DDDDD, and desires to take credit for implementing energy conservation measures, compliance should be demonstrated by using emission reduction credits according to Eqs. (14) and (15) in Sect. 63.7533 of Subpart DDDDD.

A. Emission Credits

An emission credit results from Eq. (14) of the rule.

$$ECredits = \left(\sum_{i=1}^{n} EIS_{iactual} \right) \div EI_{baseline} \qquad (14)$$

where

ECredits	=	Energy input savings for all energy conservation measures implemented for an affected boiler, expressed as a decimal fraction of the baseline energy input;
$EIS_{iactual}$	=	Energy input savings for each energy conservation measure, i, implemented for an affected boiler, million Btu per year;
$EI_{baseline}$	=	Energy input baseline for the affected boiler, million Btu per year;
n	=	Number of energy conservation measures included in the emissions credit for the affected boiler.

Emission credits are applied using Eq. (15) from the rule, as follows.

$$E_{adj} = E_m \times (1 - ECredits) \tag{15}$$

where

E_{adj}	=	Emission level adjusted by applying the emission credits earned, lb per million Btu steam output for the affected boiler;
E_m	=	Emissions measured during the performance test, lb per million Btu steam output for the affected boiler. This measurement should be made after completion of the boiler tune-up so that any improvements in boiler efficiency will be included in this baseline;
ECredits	=	Emission credits from Eq. (14) for the affected boiler.

Changes in four areas of a steam system can result in reducing fuel consumption, as can be seen in Fig. 1.

1. Generation – More efficient fuel combustion and boiler operation
2. Distribution – Reduce leaks and faulty steam traps, improve insulation and condensate return
3. Reduce or eliminate inappropriate steam usage in the connected steam system to reduce the load on the boiler
4. Recover or increase the amount of condensate returned to the boiler

This document focuses on energy credits from savings from steam system improvements. The rule, however, also notes that savings from energy improvements in process heaters can result in energy credits. While many of the principles are the same, the scope of this document does not address process heating improvements.

3. ENERGY EFFICIENCY/EMISSION REDUCTION MEASURES

Steam systems vary in complexity from relatively simple to complex; to accurately estimate and quantify the energy savings of potential improvement opportunities can be a very challenging task.

Complex analysis may not be always necessary for relatively simple steam systems, especially those that do not have cogeneration applications (steam turbines, heat recovery steam generators, etc.). In most systems, the level of analysis required is mainly to estimate the changes or improvements or savings of steam, fuel energy, and fuel consumed from implementing an energy savings opportunity. For those types of analyses, a simple methodology based on thermodynamics and the fundamental laws of conservation of mass and energy has been developed and will be provided in the following sections.

Complicated steam systems in plants or facilities are different. They require a "systems approach" and a rigorous model, such as the U.S. Department of Energy's (DOE's) Steam System Assessment Tool (SSAT), to understand the interactions and impacts of change on the whole system. These models are based on thermodynamics and the fundamental laws of mass and energy balance. Thus, they allow the use of measured parameters such as pressure, temperature, and flow to quantify the energy content of a change with reasonable accuracy rather than relying on the use of inaccurate estimates. They incorporate sophisticated algorithms to solve several equations simultaneously to converge on solutions. The fidelity of these models dictates the accuracy of the analysis and the steam system balance. It has to be noted that the boiler-related energy savings opportunities, specifically those that directly are impacted by excess air optimization and heat recovery, are not covered in this section. This is because they are already part of a tune-up analysis that has to be done prior to setting a baseline for fuel and fuel energy consumed by the steam system. Hence, this Efficiency Credit Guidance document addresses the opportunities mentioned below and provides a methodology to estimate and quantify the fuel saved by implementing those recommendations.

The following seven discussions do not represent the entirety of possible energy savings opportunities. They represent the opportunities most often discovered and implemented (within the system boundaries identified in Fig. 2), as determined during energy savings assessments conducted for DOE under the Save Energy NOW program or through the Industrial Assessment Centers. Tabular data listed in the Appendix provide estimates of the fuel savings potential available from implementing the recommended changes to the system for three boiler size categories and show average savings and payback opportunity.

1. Recover energy from boiler
2. Optimize boiler blowdown
3. Improve insulation on the steam distribution system
4. Implement a steam leak management program
5. Implement a steam trap management program
6. Reduce end-use steam requirements
7. Improve condensate recovery

For all of these guidance document write-ups, the format is the same. It first provides a description of the opportunity followed by the type of measurements (and information) that will be required from the field to quantify the savings opportunity. It then provides the actual methodology with mathematical equations to estimate the savings. To ensure that the user is aware of limitations while using this methodology, the write-up provides information on when this estimation methodology cannot be used or on exceptions to fully realize the potential savings possible. Lastly, it provides a range of the savings possible and typical paybacks for these opportunities. References are also provided for further follow-up.

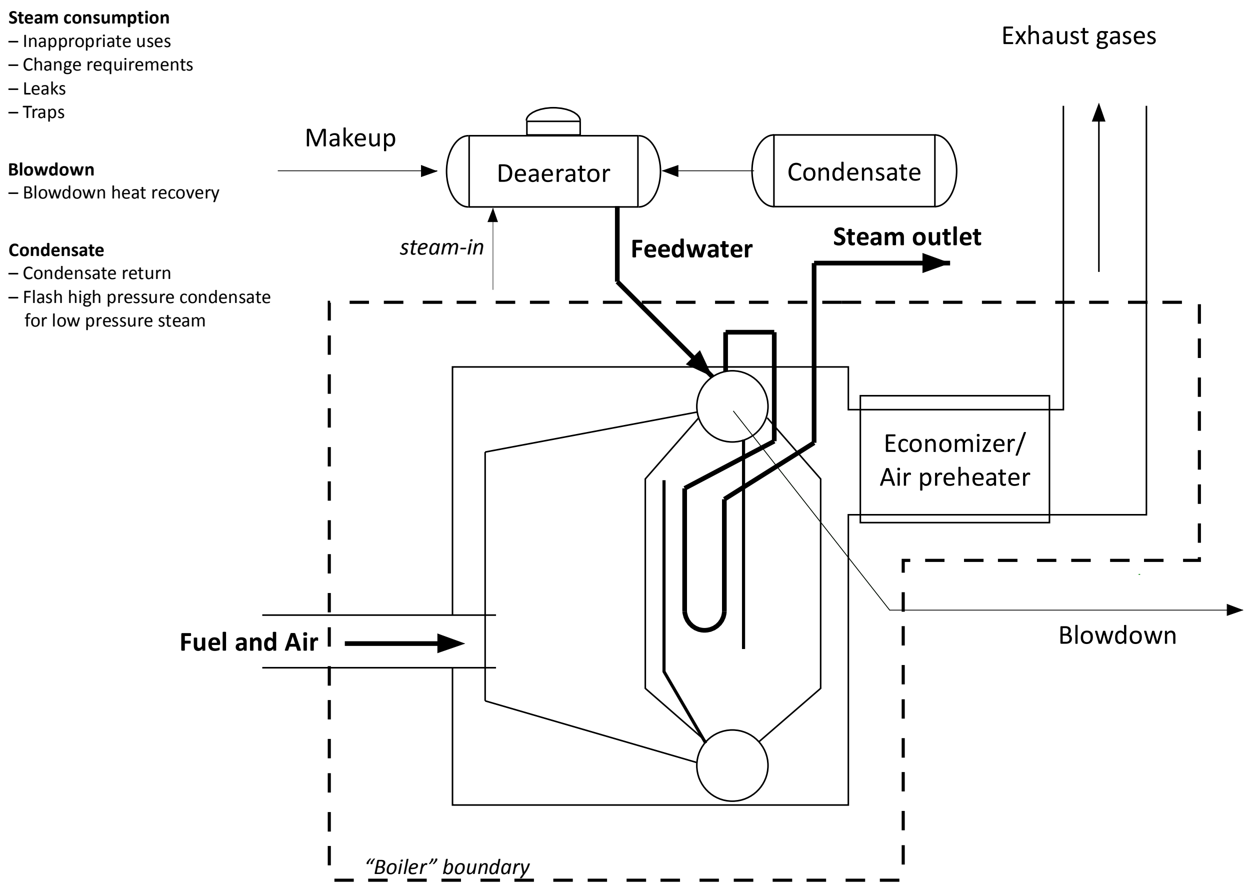

Fig. 2. Areas affected by energy savings opportunities.

3.1 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #1, RECOVER ENERGY FROM BOILER BLOWDOWN

3.1.1 Description

Boiler blowdown is saturated liquid at boiler pressure. Hence, there is a significant amount of thermal energy associated with blowdown. As blowdown is discharged from the boiler, this thermal energy (which was provided by the fuel in the boiler) is lost. Virtually all of the thermal energy resident in the boiler blowdown can be recovered using a combination of two simple methodologies:

- Flash steam recovery
- Makeup water preheating

The high-pressure blowdown stream is first flashed into a pressure vessel (flash tank) operating at low pressure (typically slightly above deaerator pressure). Part of the blowdown liquid flashes to steam at the lower pressure. This flash steam is clean and can feed the low-pressure steam header or supply steam to the deaerator or feedwater heating system. The liquid that remains in the flash vessel is at the saturation temperature (>212°F) and can still be used to preheat makeup water through the use of a heat exchanger. The blowdown water is eventually discharged from the system at a temperature very close to the inlet makeup water (or ambient) temperature. Hence, the blowdown energy loss can be virtually eliminated with very simple, robust equipment. Figure 3 provides a schematic of the blowdown energy recovery system.

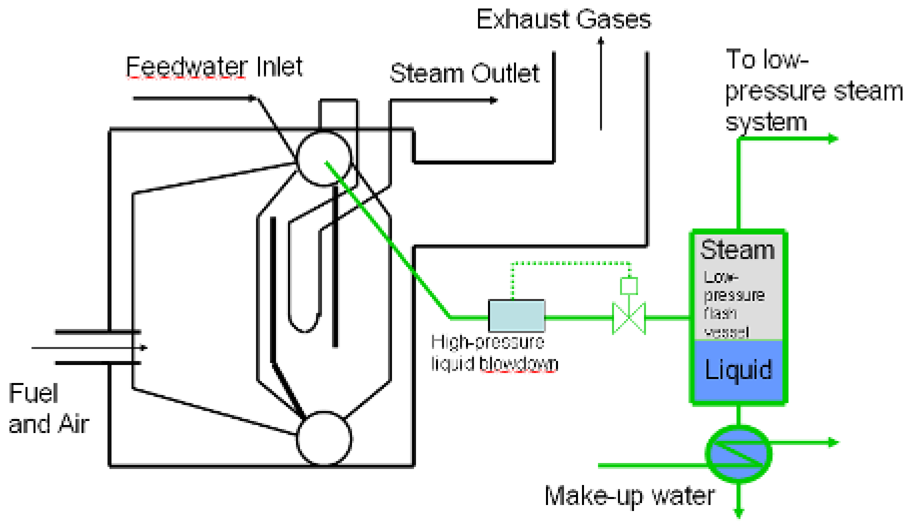

Fig. 3. Blowdown energy recovery. (Courtesy: DOE ITP Steam BestPractices End User Training Program.)

From an equipment perspective, the flash tank is a very simple unit and can be procured at minimal capital cost. Even though heat exchangers for this service are relatively simple devices, they must be selected carefully. The heat exchanger applied in this service must be capable of being cleaned because the blowdown stream can foul the heat exchange surface. Two types of heat exchangers have been observed to perform well in this application:

- Shell-and-tube straight-tube heat exchanger with blowdown on the tube-side
- Plate-and-frame heat exchanger

3.1.2 Field Measurements

- Feedwater conductivity (or TDS, or chloride concentration, or other suitable chemical constituent)
- Boiler water conductivity (or TDS, or chloride concentration, or other suitable chemical constituent)
- Steam flow rate (or feedwater flow rate)
- Boiler efficiency (combustion efficiency at a minimum)
- Boiler operating pressure
- Makeup water temperature
- Deaerator pressure (or low-pressure steam pressure)

3.1.3 Energy Savings Calculation Method

The fuel energy savings possible with flash steam recovery and makeup water preheating can be predicted manually and are presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

In order to identify the amount of thermal energy resident in the blowdown stream, the blowdown flow rate must be determined. Utilizing conventional flow meters for measuring blowdown flow is difficult because blowdown is saturated liquid that will flash at the slightest pressure drop. Most flow meter devices will impose a sufficient pressure drop that results in two-phase flow which is impossible to measure. Hence, in order to measure blowdown, the concentration of a certain chemical component in the feedwater and in the boiler water is measured. The chemical component measured in the analysis must be of sufficient concentration to allow an accurate measurement. The ratio of that chemical's concentration in the feedwater to its concentration in the boiler water is used to establish the blowdown rate. Blowdown fraction (β) is expressed as a percent of feedwater flow (m_{fw}).

$$\beta = \frac{Blowdown\ Flow}{Feedwater\ Flow} = \frac{m_{blowdown}}{m_{feedwater}} \approx \frac{Feedwater\ Conductivity}{Blowdown\ Conductivity}$$

Often, the steam flow rate (m_{steam}) from the boiler is measured (or is estimated). When this is the case, the mass flow rate of blowdown ($m_{blowdown}$) is calculated as follows:

$$m_{blowdown} = \left(\frac{\beta}{1-\beta}\right) m_{steam}$$

In most industrial steam systems, blowdown discharged from the system is replaced with relatively low-temperature makeup water. Makeup water is combined with condensate, and steam is used to heat the mixture in the deaerator. Hence, from a system perspective, blowdown is actually replaced by makeup water that is at ambient conditions (and not at feedwater conditions). The system blowdown energy loss and fuel energy savings can be estimated as follows:

$$Q_{bd\_system} = m_{blowdown}\left(h_{bd} - h_{mu}\right)$$

$$E_{fuel\_saved} = \left(\frac{Q_{bd\_system}}{\eta_{boiler}}\right)$$

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}}\right)$$

If the investigation is broken down into flash recovery and heat exchanger recovery or if approach temperature difference is part of the discussion, then the following methodology can be used.

First, the amount of flash steam formed is determined from a mass-and-energy balance on the flash tank.

$$m_{flash} = m_{blowdown}\left(\frac{h_{bd} - h_L}{h_V - h_L}\right)$$

Flash steam formed in the low-pressure flash vessel will displace makeup water that would be supplied to the system at a relatively low temperature. The calculation provided below identifies the energy savings associated with flash steam recovery.

$$Q_{bd\_flash} = m_{flash}\left(h_V - h_{mu}\right)$$

$$E_{fuel\_saved\_flash} = \left(\frac{Q_{bd\_flash}}{\eta_{boiler}}\right)$$

$$m_{fuel\_saved\_flash} = \left(\frac{E_{fuel\_saved\_flash}}{HHV_{fuel}}\right)$$

The enthalpy of the flash steam (h_{flash}) is taken as saturated vapor at flash vessel pressure. The enthalpy of the makeup water (h_{mu}) is the low-temperature replacement water to the system. Likewise, the potential savings opportunity associated with thermal energy recovery from the liquid blowdown exiting the flash vessel can be determined through simple measurements. The savings is estimated by determining the amount of recoverable energy in the liquid blowdown. The amount of blowdown liquid exiting the flash tank is the remainder after the flash steam has been recovered to the deaerator.

The heat exchanger approach temperature difference must be assumed or estimated. In other words, the temperature difference between the liquid blowdown exit and the makeup water inlet is the approach temperature difference. The approximate savings potential is provided below.

$$Q_{bd\_HX} = \left(m_{blowdown} - m_{flash}\right)\left(h_L - h_{bd\_HXout}\right)$$

$$E_{fuel\_saved\_HX} = \left(\frac{Q_{bd\_HX}}{\eta_{boiler}}\right)$$

$$m_{fuel\_saved\_HX} = \left(\frac{E_{fuel\_saved\_HX}}{HHV_{fuel}}\right)$$

3.1.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there may be some exceptions to fully realizing these energy savings. These could include:

- High condensate recovery (>90%) applications that return high temperature water
- Installations with condensing economizers that currently preheat the makeup water upstream of the deaerator
- Systems with backpressure steam turbines

Typical energy savings from this opportunity: 0.3–2.0% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.6–2.0 years

3.1.5 Key References

DOE Steam Tip, "Recover Heat from Boiler Blowdown," http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam10_boiler_blowdown.pdf

Steam System Survey Guide, http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008 http://www1.eere.energy.gov/manufacturing/tech_deployment/partners/large_plant_assessments.cfm

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

3.1.6 Nomenclature

E_{fuel_saved} – fuel energy saved

$E_{fuel\_saved\_flash}$ – fuel energy saved by implementing the flash vessel steam recovery
$E_{fuel\_saved\_HX}$ – fuel energy saved by implementing the blowdown heat exchanger
HHV_{fuel} – higher heating value of fuel
h_{bd} – enthalpy of blowdown stream
h_{bd_HXout} – enthalpy of blowdown liquid exiting the blowdown heat exchanger
h_L – saturated liquid enthalpy at the flash vessel pressure
h_{mu} – enthalpy of makeup water
h_V – saturated vapor enthalpy at the flash vessel pressure
$m_{blowdown}$ – mass flow rate of blowdown from the boiler
m_{flash} – flash steam created in flash vessel from blowdown
m_{fuel_saved} – saved fuel flow rate
$m_{fuel\_saved\_flash}$ – saved fuel flow rate due to flash steam recovery
$m_{fuel\_saved\_HX}$ – saved fuel flow rate due to blowdown heat exchanger
m_{steam} – mass flow rate of steam from the boiler
Q_{bd_flash} – thermal energy recovered by flash steam
Q_{bd_HX} – thermal energy recovered by blowdown heat exchanger
Q_{bd_system} – system blowdown thermal energy content loss

Greek Symbols

β – boiler blowdown ratio as a fraction of feedwater mass flow rate
η_{boiler} – boiler efficiency

3.2 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #2, OPTIMIZE BOILER BLOWDOWN

3.2.1 Description

Boiler feedwater is treated makeup water and condensate. However, there are still dissolved chemicals in boiler feedwater which do not exit the boiler with steam because they are not soluble in steam. As a result, the concentration of these chemicals increases in the boiler. Elevated concentrations of chemicals in boilers can result in serious operational problems, and boiler integrity can be damaged. These problems could include, but not limited to, foaming resulting in liquid carryover, scaling on the water-side of the tubes resulting in tube leaks and failures, loose sludge in the boiler water, etc.

Blowdown is the primary mechanism that controls the water chemistry of the boiler water. Blowdown is the removal of liquid water from the boiler to maintain proper water chemistry. Blowdown controls the concentration of dissolved and precipitated chemicals in the boiler and ensures that the boiler functions reliably and does not have an unplanned shutdown or failure. Boiler blowdown is saturated liquid at boiler pressure. Hence, there is a significant amount of thermal energy associated with blowdown. As blowdown is discharged from the boiler, this thermal energy (which was provided by the fuel in the boiler) is lost. Blowdown is primarily dependent on two factors:

- Boiler operating pressure
- Quality of feedwater entering the boiler

Insufficient blowdown could lead to carryover of boiler water into the steam, or the formation of corrosive products in the boiler. Excessive blowdown, however, will waste energy, water, and chemicals in the steam system. The optimum blowdown rate for a boiler is determined by factors including boiler type, boiler operating pressure, water treatment requirements, and quality of the makeup water provided to the boiler. Appropriate boiler blowdown rates can range from 1 to 6% of boiler feedwater flow rates, and can be as high as 10% when makeup water has high solids content.

Generally, blowdown is controlled based on boiler water conductivity. Conductivity is a direct measurement that can continuously provide an indication of boiler water quality. However, conductivity must be correlated to individual chemical contaminants through periodic water analysis. Conductivity and the results of specific boiler water testing aid in adjusting the blowdown rate.

Boiler blowdown can be reduced by one or more of the following modifications to the steam system:

- Implementing an automatic boiler blowdown controller
- Improving the makeup water quality by adding demineralizers, reverse osmosis, etc. to the water treatment plant
- Improving condensate recovery

3.2.2 Field Measurements Required

- Feedwater conductivity (or TDS, or chloride concentration, or other suitable chemical constituent)
- Boiler water conductivity (or TDS, or chloride concentration, or other suitable chemical constituent)
- Steam flow rate (or feedwater flow rate)
- Boiler efficiency (combustion efficiency at a minimum)
- Boiler operating pressure
- Makeup water temperature

3.2.3 Energy Savings Calculation Method

The fuel energy savings possible with reducing boiler blowdown are presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

In order to identify the amount of thermal energy resident in the blowdown stream, the blowdown flow rate must be determined. Utilizing conventional flow meters for measuring blowdown flow is difficult because blowdown is saturated liquid that will flash at the slightest pressure drop. Most flow meter devices will impose a sufficient pressure drop that results in two-phase flow which is impossible to measure. Hence, in order to measure blowdown, the concentration of a certain chemical component in the feedwater and in the boiler water is measured. The chemical component measured in the analysis must be of sufficient concentration to allow an accurate measurement. The ratio of that chemical's concentration in the feedwater to its concentration in the boiler water is used to establish the blowdown rate. Blowdown fraction (β) is expressed as a percent of feedwater flow (m_{fw}).

$$\beta = \frac{Blowdown\ Flow}{Feedwater\ Flow} = \frac{m_{blowdown}}{m_{feedwater}} \approx \frac{Feedwater\ Conductivity}{Blowdown\ Conductivity}$$

Often, the steam flow rate (m_{steam}) from the boiler is measured (or is estimated). When this is the case, the current mass flow rate of blowdown ($m_{blowdown\_current}$) is calculated as follows:

$$m_{blowdown\_current} = \left(\frac{\beta_{current}}{1 - \beta_{current}} \right) m_{steam}$$

After optimizing the blowdown fraction (β_{new}) required for the boiler, the new mass flow rate of blowdown ($m_{blowdown\_new}$) is calculated as follows:

$$m_{blowdown\_new} = \left(\frac{\beta_{new}}{1-\beta_{new}} \right) m_{steam}$$

In most industrial steam systems, blowdown discharged from the system is replaced with relatively low-temperature makeup water. Makeup water is combined with condensate and steam is used to heat the mixture in the deaerator. Hence, from a system perspective, blowdown is actually replaced by makeup water which is at ambient conditions (and not at feedwater conditions). The energy savings due to optimizing the blowdown can be estimated as follows:

$$Q_{blowdown} = \left(m_{blowdown\_current} - m_{blowdown\_new} \right)\left(h_{bd} - h_{mu} \right)$$

The energy supplied to the blowdown stream is from the boiler fuel and, hence, the fuel energy savings and the fuel saved can be calculated from the blowdown energy savings by including the boiler inefficiencies as follows:

$$E_{fuel\_saved} = \left(\frac{Q_{blowdown}}{\eta_{boiler}} \right)$$

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}} \right)$$

There are two assumptions that have been made in the above calculations methodology to keep the analysis simple without a significant loss in the accuracy of the results. These include:

- Mass flow rate of steam remained the same before and after optimizing the blowdown rate
- Boiler efficiency remained the same before and after optimizing the blowdown rate

3.2.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there are exceptions to realizing these energy savings. These systems include:

- Blowdown energy recovery using a combination of one or both of the following:
  - Flash steam recovery vessel
  - Blowdown heat recovery exchanger

Typical energy savings from this opportunity: 0.3–1.5% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.6–5.0 years

3.2.5 Key References

DOE Steam Tip, "Minimize Boiler Blowdown,"
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam9_blowdown.pdf

Steam System Survey Guide,
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

CRTD, Volume 34, "Consensus on Operating Practices for the Control of Feedwater and Boiler Water Chemistry in Modern Industrial Boiler," ASME, 1998.

3.2.6 Nomenclature

E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
h_{bd} – enthalpy of blowdown stream
h_{mu} – enthalpy of makeup water
$m_{blowdown\_current}$ – mass flow rate of blowdown from the boiler before optimizing blowdown
$m_{blowdown\_new}$ – mass flow rate of blowdown from the boiler after optimizing blowdown
m_{fuel_saved} – saved fuel flow rate
m_{steam} – mass flow rate of steam from the boiler
$Q_{blowdown}$ – thermal energy saved by optimizing boiler blowdown rate

Greek Symbols

$\beta_{current}$ – boiler blowdown ratio as a fraction of feedwater mass flow rate before optimizing blowdown
β_{new} – boiler blowdown ratio as a fraction of feedwater mass flow rate after optimizing blowdown
η_{boiler} – boiler efficiency

3.3 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #3, IMPROVE INSULATION ON THE STEAM DISTRIBUTION SYSTEM

3.3.1 Description

Steam systems operate above ambient temperatures and will always lose thermal energy (or heat). Heat loss to the ambient from a pipe or surface occurs via two modes of heat transfer:

- Convection (natural or forced)
- Radiation

Both radiation and natural convection heat transfer mechanisms contribute to heat loss for pipes and surfaces that are indoors. With applications that are outdoors and are subject to wind, forced convection heat transfer dominates when steam temperatures are less than 350°F. As steam temperatures exceed these levels, radiation heat transfer becomes a significant factor. Both forced convection and radiation heat transfer loss mechanisms exist and need to be considered in the evaluations.

Improving insulation comes under continuous facility maintenance and should be appraised periodically in all steam plants and facilities. Insulation is extremely important on steam systems for the following reasons:

- Plant personnel safety
- Minimizing energy losses

- Maintaining steam conditions for process end-use requirement
- Protecting equipment, piping, etc. from ambient conditions
- Preserving overall system integrity

There are several reasons for damaged or missing insulation including:

- Missing insulation due to maintenance activities
- Missing/damaged insulation due to abuse
- Damaged insulation due to accidents
- Normal wear and tear of insulation due to ambient conditions
- Valves and other components not insulated because no insulation was specified at design

The most common areas of missing or damaged insulation include:

- Steam distribution headers
- Valves
- Inspection man-ways
- End-use equipment
- Storage tanks and vessels
- Condensate return lines

Different kinds of insulation materials are used in steam distribution systems, and the type of insulation material to be used is mainly dictated by the steam temperature and application. Each plant or facility will have insulation specifications primarily based on temperature, pipe size, and location (inside or outside). Irrespective of the type of insulation, heat transfer loss reduces exponentially as insulation thickness increases. Hence, there is a diminishing economic return, and a certain level of optimum insulation thickness exists for each application, which is dependent on several factors including, but not limited to, steam temperature, material of insulation, fuel cost, and pipe size.

Insulation repair and maintenance in industrial plants may be outsourced, and often it is cost effective to repair at the same time several areas in need of insulation. This implies that plant and facility personnel should periodically undertake an insulation appraisal (audit) of their plant and identify the major areas that would benefit by upgrading or adding insulation. This should be a continuous activity to be done on a periodic basis and will ensure that the steam system is always well insulated and having minimal heat losses.

It has to be noted that although insulation is being discussed here in the context of "steam distribution," it has impacts in all the steam areas. The main reason for discussing it in the "distribution" area is because it has the greatest impact in a steam distribution system.

3.3.2 Field Measurements and Other Information Required

- Steam temperature
- Steam pressure
- Ambient temperature
- Pipe size and length of uninsulated pipe (or an estimate of uninsulated area)
- Geometry and orientation of uninsulated pipe or area
- Wind speed
- Thermal conductivity of pipe (or uninsulated area)
- Heat transfer resistance of insulation material to be used

- Emissivity of jacket material (if any)
- Boiler efficiency (combustion efficiency at a minimum)
- Makeup water temperature

3.3.3 Energy Savings Calculation Method

The fuel energy savings possible with improving insulation on the distribution system are presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations

A first-order determination of the amount of energy and fuel saved from insulating areas in the steam distribution system will provide the basis for determining the need for undertaking an insulation project.

A first-order heat transfer model can be developed and used to determine the convective (natural and/or forced) and the radiation heat transfer energy losses that exist from all the areas that are either uninsulated or poorly insulated. This can be cumbersome and will require heat transfer correlations that will vary based on geometry and the modes of convective heat transfer, either natural or forced. Nevertheless, an analysis must be completed to determine the energy and fuel saved at the boiler by insulating areas on the steam distribution system. Many empirical and computerized tools are available to aid in the evaluation of insulation projects. One such tool is the 3EPlus® insulation evaluation software developed by the North American Insulation Manufacturers Association (NAIMA). 3EPlus® has been pre-populated with ~30insulation materials including their thermal properties. Additionally, several different materials and jackets (with different emissivity) are also included in the software to allow the user to use drop-down menus to select specific materials for their applications. Lastly, different geometries and applications can be modeled in the software.

The 3EPlus® insulation thickness computer program will be used here to determine the heat loss from bare pipe or surface (Q_{bare}) and heat loss from insulated pipe or surface ($Q_{insulated}$). Provided in Figs. 4 and 5 are the input and output screens, respectively, of the 3EPlus® program when used to calculate heat transfer energy loss from a bare and insulated pipe.

The input screen (Fig. 4) has several drop-down boxes that provide a user-friendly ability to input all the information required to determine the heat loss from the bare pipe (or surface) and the insulated pipe (or surface).

The output screen (Fig. 5) is also self-explanatory and provides information on the surface temperature, heat loss, and insulation efficiency for different insulation thicknesses. The first row in the results table always indicates the bare pipe (or surface) heat loss provided in terms of heat loss per linear foot (or per square feet for a surface). The remainder of the rows indicate the insulated pipe (or surface) heat loss provided in terms of heat loss per linear foot (or per square feet for a surface) for different insulation thicknesses starting from 0.5 inch and in increments of 0.5 inch. The thickness of insulation to be chosen may be based on energy savings, safety concerns for personnel, economics, etc. All the information required for determining the energy and fuel savings that would result from improving insulation on the steam distribution system can be obtained from 3EPLus®.

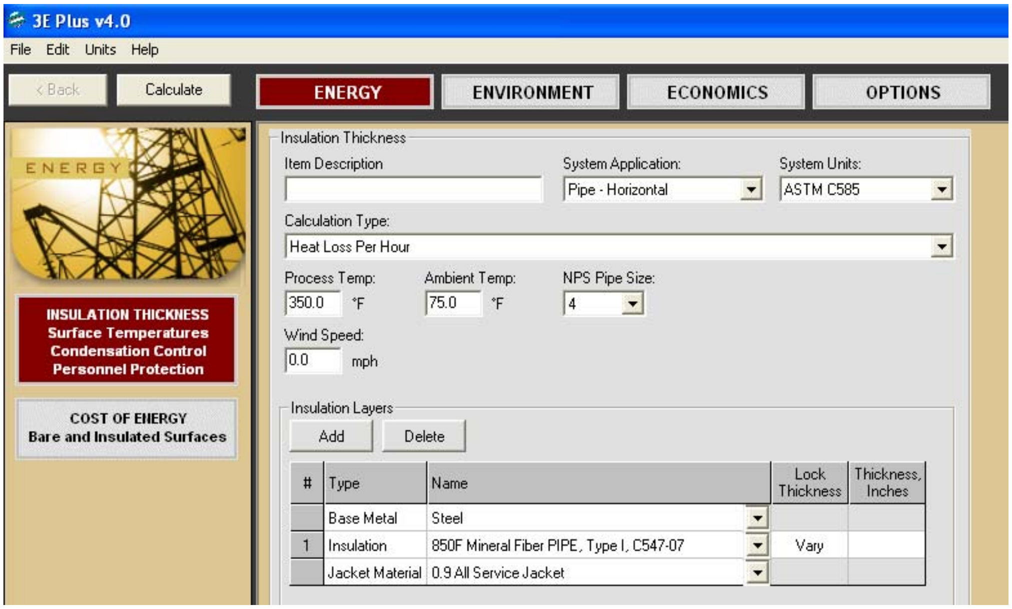

Fig. 4. Input screen of 3EPlus® insulation software program.

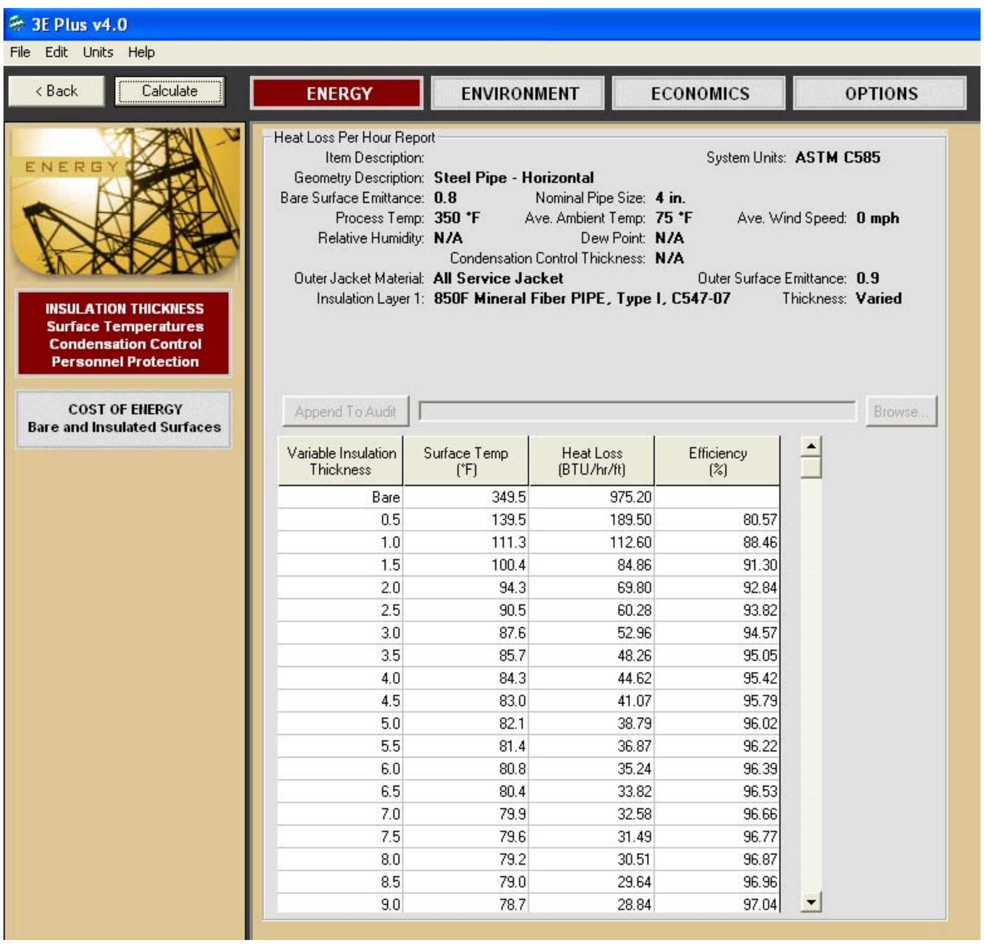

Fig. 5. Output screen of 3EPlus® insulation software program.

The energy savings for adding insulation on an uninsulated pipe can be calculated as follows:

$$Q_{saved\_Insulation} = \left(Q_{bare} - Q_{insulated}\right) \times Length$$

Similarly, the energy savings for adding insulation on an uninsulated surface can be calculated as follows:

$$Q_{saved\_Insulation} = \left(Q_{bare} - Q_{insulated}\right) \times Area$$

The fuel energy savings and fuel savings can then be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{Q_{saved\_insulation}}{\eta_{boiler}}\right)$$

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}}\right)$$

If additional due-diligence is needed, then the insulation energy savings ($Q_{saved\_insulation}$) can be used to calculate the amount of steam that would have condensed if this insulation did not exist on the pipe (or surface). To calculate these steam savings, it is assumed that saturated condensate will be produced at the header pressure and will be removed by properly working steam traps from the header.

$$m_{saved\_steam} = \frac{Q_{saved\_Insulation}}{\left(h_{steam} - h_{cond}\right)}$$

where h_{steam} is the enthalpy of steam and h_{cond} is the enthalpy of saturated condensate in the header.

If this condensate from the headers is removed and returned to the boiler plant, then the fuel energy saved at the boiler can be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{m_{saved\_steam}\left(h_{steam} - h_{cond}\right)}{\eta_{boiler}}\right)$$

If this condensate from the headers is removed but dumped to sewers and not returned to the boiler plant, then the fuel energy saved at the boiler can be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{m_{saved\_steam}\left(h_{steam} - h_{mu}\right)}{\eta_{boiler}}\right)$$

The fuel savings for improving insulation on the steam distribution system is calculated as follows:

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}}\right)$$

3.3.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there are exceptions to realizing these energy savings. These systems include:

- Cogeneration systems that have back-pressure steam turbine operations
- Multi-pressure complex steam distribution systems that may involve flash steam recovery, etc.

Typical energy savings from this opportunity: 0.0–3.0% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.2–1.0 year

3.3.5 Key References

DOE Steam Tip, "Insulate Steam Distribution and Condensate Return Lines," http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam2_insulate.pdf

DOE Steam Tip, "Install Removable Insulation on Valves and Fittings," http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam17_valves_fittings.pdf

Steam System Survey Guide, http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

3EPLus® Insulation Software Program, Version 4, Build 39, North American Insulation Manufacturers Association (NAIMA), http://www.pipeinsulation.org

3.3.6 Nomenclature

Area – Surface area to be insulated
E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
h_{cond} – enthalpy of condensate
h_{mu} – enthalpy of makeup water
h_{steam} – enthalpy of steam
Length – length of pipe to be insulated
m_{saved_steam} – mass flow rate of steam saved by insulating pipe (or surface)
m_{fuel_saved} – saved fuel flow rate
Q_{bare} – thermal energy loss from bare pipe (or surface)
$Q_{insulated}$ – thermal energy loss from insulated pipe (or surface)
$Q_{saved\_insulation}$ – thermal energy saved by insulating pipe (or surface)

Greek Symbol

η_{boiler} – boiler efficiency

3.4 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #4, IMPLEMENT A STEAM LEAK MANAGEMENT PROGRAM

3.4.1 Description

Steam is a very energy intensive and expensive utility for facilities and plants. A steam system is divided into four areas: generation, distribution, end use, and recovery. As steam passes through each of these areas, it goes through pipes, headers, mechanical equipment, heat exchangers, valves, piping components, etc. As a result of normal wear and tear and thermal cycling of these individual components and of the whole steam system, steam leaks develop and can result in significant energy losses. Steam leaks occur everywhere in the steam system but the most common places for steam leaks are:

- Flanges and gasketed joints
- Pipe fittings
- Valve stems and packings
- Steam traps
- Relief valves
- Pipe failures

Steam leaks from pipe failures can be a major source of steam loss in any plant or facility. However, these typically present a "safety issue," especially if they are in close proximity to plant personnel frequented areas and get fixed immediately. But those steam leaks that are in remote locations such as pipe racks do not get noticed and can remain there forever.

Steam trap failures also account for a large portion of the leaks within a plant or facility having a very wide steam distribution network and multiple end users. Steam trap failure leaks are more difficult to observe than pipe failure leaks, especially since most steam traps discharge into a closed condensate system.

Typically, the steam loss magnitude through a leak is difficult to determine unless a proper procedure is followed. Several theoretical and empirical methods have been developed to provide a gross estimate of the steam loss including, but not limited to:

- Napier's choked flow equation
- Plume height measurement
- Using a pitot tube to measure the steam velocity from an open pipe
- Ultrasonic techniques with manufacturers' protocols for steam traps
- Thermodynamic mass and energy balance methodologies

Nevertheless, in most instances an order of magnitude of the steam leak is all that is necessary to justify the repair of the steam leak. Other factors that are typically considered for justifying (or not justifying) the steam leak repair include safety, ability to isolate the leak, process disruption, etc.

A first step in implementing a steam leaks management program is a steam leak audit, which identifies all the steam leaks in a plant or facility and creates a prioritized list based on steam pressure, size of the leak, safety, etc. The second step is to estimate the amount of fuel energy and fuel saved from eliminating each of these steam leaks. The sum of all the fuel energy and fuel saved from eliminating all the steam leaks or those that account for 80% of the fuel energy and fuel saved will provide the justification for implementing a steam leaks management program.

Steam leaks occur over time, and it is important to realize that repairing steam leaks once and forgetting about them is not the solution to optimizing a steam system. It is anticipated that a continuous steam leaks management program be put in place that can continuously monitor and repair steam leaks periodically. A continuous steam leak maintenance program based on finding (periodic surveying), tagging, and eliminating steam leaks is essential to the efficient operation of a steam system. Most times, such maintenance programs are questioned in the plant or facility as regards their cost-effectiveness and overall impact to operations. But it has been observed and proven in all instances that having a steam leaks management program can be very beneficial both from a perspective of improving the overall steam system energy efficiency as well as from a reliable operations perspective for any steam plant or facility.

3.4.2 Field Measurements and Other Information Required

- Steam generation temperature
- Steam generation pressure
- Steam header pressure where leak exists
- Estimate of area of orifice of steam leak (typically approximate diameter of orifice)
- Boiler efficiency (combustion efficiency at a minimum)
- Makeup water temperature

3.4.3 Energy Savings Calculation Method

The fuel energy savings possible by eliminating a steam leak is presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

As mentioned earlier, there are theoretical, empirical, and practical methodologies to calculate (estimate) the steam loss from a leak. The Napier's choked flow equation is one such methodology that allows for estimating the steam leakage flow of saturated steam through a well-rounded orifice for a given operating pressure and the orifice size. The Napier's choked flow equation is as follows:

$$m_{steam} = 51.43 \times A_{orifice} \times P_{steam}$$

where m_{steam} is steam leakage flow rate (lb/hr), $A_{orifice}$ is the area of the orifice through which the steam is leaking (in^2), and P_{steam} is the header pressure (psia). It has to be noted that this relationship is only valid for choked flow conditions, which is when the exit pressure is less than 0.51 times the header pressure. Additionally, this relationship is valid for a well-rounded orifice. A sharp-edged orifice will experience a flow of ~60% of this "well-rounded" flow.

Since this steam is lost to ambient, there is no condensate available (or created) to be returned and, hence, all the leaked amount of steam is replaced by makeup water in the boiler. The fuel energy savings and fuel savings can then be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{m_{steam}\left(h_{steam} - h_{mu}\right)}{\eta_{boiler}} \right)$$

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}} \right)$$

3.4.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there are exceptions to realizing these energy savings. These systems include:

- Cogeneration systems that have back-pressure steam turbine operations
- Multi-pressure complex steam distribution systems that may involve flash steam recovery, etc.
- Steam systems operating at 15 psig or less
- Steam trap leaks and other system leaks that end up in closed condensate systems or flash tanks that recover steam

Typical energy savings from this opportunity: 0.0–2.0% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.0–0.5 years

3.4.5 Key References

Steam System Survey Guide,
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

3.4.6 Nomenclature

Aorifice – area of the orifice which represents the leak
E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
h_{mu} – enthalpy of makeup water
h_{steam} – enthalpy of steam generated by the boiler
m_{steam} – mass flow rate of steam leaking through the orifice
m_{fuel_saved} – saved fuel flow rate
P_{steam} – header pressure at the steam leak

Greek Symbol

η_{boiler} – boiler efficiency

3.5 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #5, IMPLEMENT A STEAM TRAP MANAGEMENT PROGRAM

3.5.1 Description

Steam traps are always a subject of major concern for reliable steam system operations. They are most often neglected due to lack of resources in plants and facilities. Steam traps serve several vital operating functions for a steam system, but the most important of them all are:

- During start-up, they allow air and large quantities of condensate to escape

- During normal operation, they allow collected condensate to pass into the condensate return system, while minimizing (or eliminating) loss of steam

There are different kinds of steam traps, so functionality and principles of operation must be understood by specifying design engineers, plant operations, and maintenance teams. The different kinds of steam traps are classified on the principles of operation as follows:[1]

- Thermostatic traps
  - Bellows
  - Bimetallic

- Mechanical traps
  - Ball float
  - Float and lever
  - Inverted bucket
  - Open bucket
  - Float and thermostatic

- Thermodynamic traps
  - Disc
  - Piston
  - Lever

- Orifice traps
  - Orifice plate
  - Venturi tube

It is vitally important to have an effective steam trap management and maintenance program in any plant or facility. There can be several hundreds of steam traps in large plants and facilities, and they should be checked periodically for proper operation. It is necessary to inspect every steam trap in the facility and determine how it is performing at least once a year. In order to investigate the steam traps, it is important to understand how each type works. Hence, these inspections should be completed by trained personnel that understand the operation of steam traps and the steam system in general. Steam trap functionality should be assessed through the use of appropriate instruments. There are several methodologies available in the industry for investigating steam trap performance such as:

- Visual
- Acoustic
- Thermal
- Online real-time monitoring

Most of the times, using any one method may not provide a conclusive answer to the proper operation of the steam trap. Hence, a combination of the above methods is recommended. Additionally, since proper training and a good understanding of steam trap operations is a pre-requisite for inspecting steam traps, out-sourcing this activity on a periodic basis is also a very good option. Most steam trap manufacturers and vendors will offer a steam trap audit service at minimal or no charge to plant or facility.

[1] It should be clearly understood that this does not constitute an endorsement of any particular type of steam trap. Steam traps should be selected based on the most appropriate design for the function required in a specific installation.

A failed-open steam trap allows “live” steam to discharge from the system and so becomes a steam leak. A failed-closed trap does not remove condensate and it backs up in the upstream equipment. If this equipment is a heat exchanger, then the process will be heat duty limited. If this trap serves a steam distribution header, then it could result in water hammer and damage components.

Unless a detailed steam trap assessment is conducted, it is difficult to potentially quantify the benefit of a steam trap management program. Nevertheless, historically and statistically it has been proven time and again that steam traps fail and if not replaced or repaired, they can be a source of significant energy waste, a cause of production woes, and affect system reliability adversely. Even a well-maintained steam system will typically experience a 10% trap failure in a 1-year period. If unchecked, this can translate into significant fuel energy losses and create operational issues in the steam system.

A first step in implementing a steam trap management program is a steam trap audit to identify all the failed steam traps in a plant or facility and create a prioritized list based on steam pressure, size of the trap, safety, criticality of operation, etc. The second step is to estimate the amount of fuel energy and fuel saved from eliminating each of the failed-open steam traps. The sum of all the fuel energy and fuel saved from fixing all the failed-open steam traps or those that account for 80% of the fuel energy and fuel saved will typically provide enough justification for implementing a steam trap management program.

The DOE SSAT offers a very high level gross estimate of potential energy and cost savings possible by implementing an effective steam trap management and maintenance program. This is based on historic failure rates of traps, number of traps in the plant, and the last time a steam trap assessment followed by repair and/or replacement of traps was conducted in the plant. Some other methodologies to estimate the amount of steam loss from a failed-open steam trap are:

- Obtain the steam trap make, model number, and orifice size, and use the manufacturer’s data to determine the steam loss based on operating conditions
- Obtain the steam trap orifice size, and use an orifice calculation (Napier’s equation) to determine the maximum steam loss based on choked flow conditions
- Use proprietary tools, software, and acoustic signatures from the steam trap to determine steam loss

3.5.2 Field Measurements and Other Information Required

- Steam generation temperature
- Steam generation pressure
- Steam header pressure where steam trap exists
- Steam trap orifice area (steam trap make and model number can provide this information also)
- Condensate return temperature (if applicable)
- Boiler efficiency (combustion efficiency at a minimum)
- Makeup water temperature

3.5.3 Energy Savings Calculation Method

The fuel energy savings possible by repairing a failed open steam trap is presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

As mentioned earlier, there are different methodologies to calculate (estimate) the steam loss from a failed-open leaking steam trap. The Napier’s choked flow equation is one such methodology that allows for estimating the steam flow of saturated steam through a well-rounded orifice for a given operating pressure and the orifice size. The Napier's choked flow equation is as follows:

$$m_{steam} = 51.43 \times A_{orifice} \times P_{steam}$$

where m_{steam} is steam leakage flow rate (lb/hr), $A_{orifice}$ is the area (in^2) of the steam trap orifice (based on steam trap size, which can be obtained from make and model number of the steam trap), and P_{steam} is the steam pressure (psia) upstream of the trap. It has to be noted that this relationship is only valid for choked flow conditions, which is when the exit pressure is less than 0.51 times the upstream steam pressure. Additionally, this relationship is valid for a well-rounded orifice. A sharp-edged orifice will experience a flow of ~60% of this "well-rounded" flow.

In most plants and facilities, steam traps discharge to a closed condensate return system. If this leaking steam enters the closed condensate return system and the condensate is returned to the boiler plant, then the fuel energy saved at the boiler can be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{m_{steam}\left(h_{steam} - h_{cond}\right)}{\eta_{boiler}} \right)$$

If the failed-open steam trap is leaking steam directly to the ambient, then all the leaked amount of steam is replaced by makeup water in the boiler. The fuel energy savings can then be calculated as follows:

$$E_{fuel\_saved} = \left(\frac{m_{steam}\left(h_{steam} - h_{mu}\right)}{\eta_{boiler}} \right)$$

The fuel saved due to this failed-open leaking steam trap can then be calculated as follows:

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}} \right)$$

3.5.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there are exceptions to realizing these energy savings. These systems include:

- Cogeneration systems that have back-pressure steam turbine operations
- Multi-pressure complex steam distribution and condensate return systems that may involve flash steam recovery, etc.
- Steam systems operating at 15 psig or less

Typical energy savings from this opportunity: 0.0–2.5% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.0–1 year

3.5.5 Key References

DOE Steam Tip, "Inspect and Repair Steam Traps,"
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam1_traps.pdf

Steam System Survey Guide,
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

3.5.6 Nomenclature

$A_{orifice}$ – area of the steam trap orifice
E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
h_{cond} – enthalpy of condensate returned (at the boiler plant or in the main condensate tank)
h_{mu} – enthalpy of makeup water
h_{steam} – enthalpy of steam generated by the boiler
m_{steam} – mass flow rate of steam leaking through the failed-open steam trap
m_{fuel_saved} – saved fuel flow rate
P_{steam} – upstream steam pressure at the steam trap

Greek Symbol

η_{boiler} – boiler efficiency

3.6 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #6, REDUCE END-USE STEAM REQUIREMENTS

3.6.1 Description

The types of steam end use vary widely across industrial, commercial, and institutional facilities and plants. As a result, it is very difficult to cover all the different types of steam end uses. Nevertheless, steam end use is the main reason for having a steam system in a plant and should not be neglected. Enough due diligence should be given to study and understand end use because optimizing steam end use can provide significant benefits both from a perspective of fuel energy and cost savings as well as production and yield improvements. Plant personnel working with steam systems should be trained to understand how steam is used in their facilities. This will allow them to optimize steam systems for their specific plant operations.

In general, steam provides the source of heat to the process. Most end uses will require a certain mass flow rate of steam which will correspond to a thermal heat load or duty (MMBtu/hr). But there are certain processes (especially in industry) that require both mass flow (heat duty) and volume flow of steam. These are typically devices that require certain steam velocity to perform the end-use functions in the plant. Although this is not a comprehensive list, some of the types of steam end use are listed here.

Steam end uses based on mass flow (heat duty) of steam:

- Heat exchangers
- Dryers
- Evaporators
- Reboilers
- Reformers
- Absorption chillers
- Humidifiers
- Preheat/reheat air handling coils

Steam end uses based on volume flow and mass flow (heat duty) of steam:

- Steam jet ejectors/eductors
- Stripping columns
- Distillation towers
- Thermocompressors

In the classic configuration, the main strategy for optimizing steam use processes is to eliminate or reduce the amount of steam used by that process. This implies improving the process efficiency, which thereby reduces steam use. Then the optimization strategy looks to using steam at as low a pressure as possible that would allow power generation while reducing pressure. Lastly, the optimization strategy would aim to shift all or part of the steam demand to a waste heat source. One other configuration of this last step would be to look for upgrading low pressure (or waste) steam to supply process demands that would have otherwise used much higher pressure steam. A couple of examples described next provide a very brief understanding of the possible opportunities that may exist in plants and facilities to reduce the amount of steam required for end uses.

A. Preheat the air/water/process streams with flash or vented steam to reduce steam use

In most steam systems, condensate is collected and routed to a condensate tank where flash steam is usually vented to the atmosphere. This flash steam can be effectively utilized to preheat either air, water, or process streams that may typically be heated with steam. This reduces the total amount of steam required for heating the air/water/process streams. Figure 6 provides a general explanation of capturing flash steam and using it for end use instead of venting it.

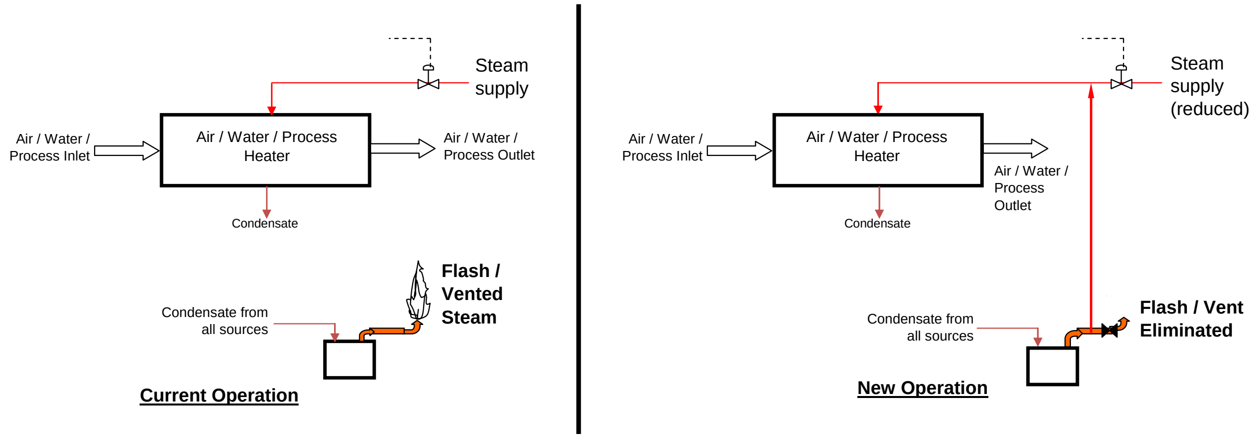

Fig. 6. Capture and use of flash steam.

The concept of using vented steam from other areas in the plant or facility is identical to the one explained above where flash steam is utilized from condensate tanks. Additionally, this same concept can be applied for waste heat recovery wherein waste heat from stack exhausts, process heat, or other sources can be used to preheat air/water/process streams and reduce the amount of steam required by the end use.

B. Reduce the stripping steam by preheating the inlet stream with an external exchanger

Stripping is a physical process in which a hot gas stream (mostly steam) traveling up, strips-off the undesirable gases from the liquid stream flowing down. The heat in the stripping steam is also used to evaporate the droplets of the down-coming liquid stream to strip off the undesirable gases. All the condensate from the steam supplied to the stripper is lost due to its direct contact with the process. If the liquid stream is already at an elevated temperature, the steam is required only for stripping purposes. If the inlet stream is preheated, steam use at the stripper would be reduced. This concept is applicable to any plant or facility that operates a steam stripping column. The stripping steam use would reduce even if vented steam, flash steam, or low steam at below 50 psig is used in the external exchanger. Additionally, condensate recovery would increase if steam is used in the external exchanger.

C. Clean heat exchangers periodically to minimize fouling

Heat exchanger fouling adversely affects the performance of the heat exchanger and may lead to higher steam use as steam pressure in the exchanger increases to account for the higher temperature driving force required to satisfy the thermal demand of the end use. By monitoring and periodically cleaning the heat exchangers, buildup of material on the heat transfer surface area is minimal. This ensures that heat exchanger performance remains at its best and close to design conditions. At these conditions steam usage is at its minimum to meet the required heat demand of the end use.

D. Use a thermocompressor to recover vented/flash/low-pressure steam

When steam is used in plants and facilities at different pressure levels, there can be several opportunities to capture and use vented/flash/low-pressure steam as medium-pressure steam. A mechanical device known as a thermocompressor can capture the vented/flash/low-pressure steam and upgrade it to medium-pressure steam by using high-pressure steam. A basic sketch of a thermocompressor is shown in Fig. 7.

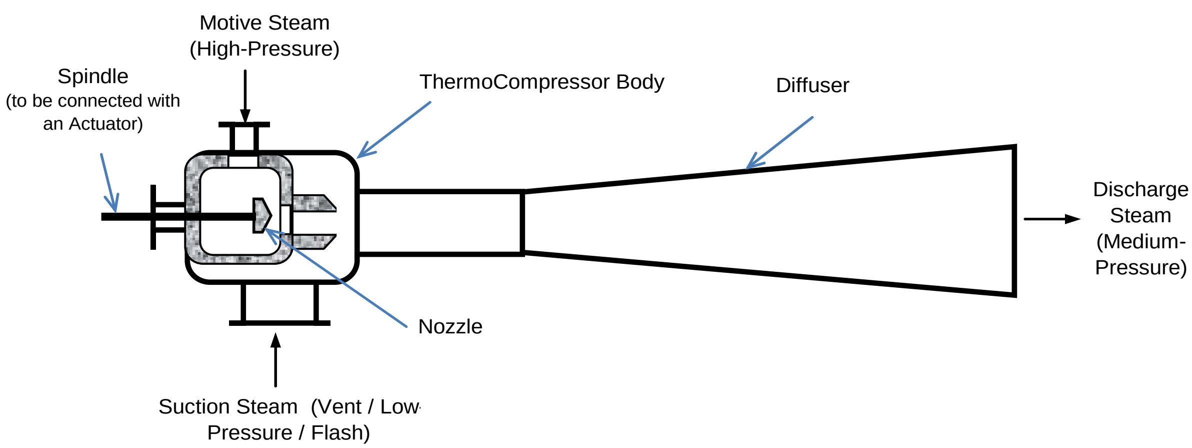

Fig. 7. A thermocompressor.

Since vented/flash/low-pressure steam is converted to usable medium-pressure steam from high-pressure steam with the help of a thermocompressor, the net steam savings would be the recovered vented/flash/ low-pressure steam less the high-pressure steam used by the thermocompressor.

3.6.2 Field Measurements and Other Information Required

Depending on the application and end use, field measurements will vary significantly. Almost all the methodologies aim to determine the amount of steam saved, and once that information is calculated (estimated), the remainder of the calculations of the fuel and the fuel energy saved are identical.

It is difficult to provide a generic methodology that can be applied to calculate the steam savings from all the possible opportunities of reducing steam end use. Nevertheless, an attempt is made here to provide a simplified analysis for calculating the steam savings for the most common steam reduction methodology, that is, *Preheat the air/water/process streams with flash or vented steam to reduce steam use* (Item A). The field measurements include:

- Inlet air/water/process temperature
- Outlet air/water/process temperature
- Mass (or volume) flow of air/water/process stream
- Density of air/water/process stream (if required)
- Specific heat of air/water/process stream
- Flash or vented steam pressure
- Feedwater temperature
- Boiler efficiency (combustion efficiency at a minimum)

3.6.3 Energy Savings Calculation Method

An example for calculating the fuel energy savings possible by reducing steam demand is presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

Very rarely is flash or vented steam metered in a steam system, and there are methodologies to evaluate these flows using thermodynamics along with condensate flows, temperatures, etc. Sometimes it is also possible to use pitot tubes and pressure drop measurements to determine the amount of vented steam. Depending on the accuracy of flow measurements, these methodologies can lead to very good estimates of flash and vented steam.

Nevertheless, the methodology most commonly applied is to calculate the heat recovered by the air/water/process streams and then apply the conservation of energy principle on the heat exchanger to calculate the equivalent steam savings.

If mass flow rate of the air/water/process stream is known, then the heat duty is given by:

$$Q_{HX} = m_{fluid} \times C_p \times (T_{out} - T_{in})$$

If volume flow rate of the air/water/process stream is known, then the heat duty is given by:

$$Q_{HX} = V_{fluid} \times \rho_{fluid} \times C_p \times (T_{out} - T_{in})$$

The steam properties of the flash or vented steam are determined from steam tables, and it is assumed that the steam trap on this heat exchanger is functioning properly and is removing all the saturated condensate from this heat exchanger. The equivalent steam savings can now be determined as follows:

$$m_{steam} = \frac{Q_{HX}}{\left(h_{flash} - h_{cond}\right)}$$

The fuel energy savings associated with these steam savings can then be estimated as follows:

$$E_{fuel\_saved} = \frac{m_{steam}\left(h_{steam} - h_{fw}\right)}{\eta_{boiler}}$$

The fuel saved from this reduction in steam end use can then be calculated as follows:

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}}\right)$$

It is very important to realize that this was a very simple but accurate methodology to estimate the fuel energy and fuel savings possible by reducing the steam required by the end use. But this was developed for a case where flash or vented steam was used to heat the air/water/process stream and reduce (or even eliminate) the steam required by the end use. A similar methodology needs to be developed for each specific end-use application to determine reduction of steam use, and that is beyond the scope of this document.

3.6.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances and end-use applications, there may be some exceptions to fully realizing these energy savings in this specific end-use application. These could include:

- When the need for heating air/water/process is reduced or not required, such as during seasonal changes or due to process changes
- When condensate temperature is reduced, so less flash steam is generated in the flash tank
- When the entering air/water/process stream is already hot and does not require heating

As other steam reduction opportunities are investigated, there may be limitations that prevent the plant or facility from realizing the complete fuel energy savings. It is extremely difficult to list all those possible conditions in a generic manner, so they are not listed here, but plant personnel are expected to do their due-diligence on the specific end-use and opportunity for steam reduction.

Typical energy savings from this opportunity: 0.1–5% of an individual facility’s annual steam system fuel energy use

Typical payback for implementing this opportunity: 0.5–2.0 years

3.6.5 Key References

DOE Steam Tip, “Use steam jet ejectors or thermocompressors to reduce venting of low-pressure steam,” http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam29_use_steam.pdf

DOE Steam Tip, “Cover heated, open vessels,”
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam19_use_steam.pdf

DOE Steam Tip, “Use low-grade waste steam to power absorption chillers,”
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam14_chillers.pdf

Steam System Survey Guide,
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Improving Steam System Performance: A Sourcebook for the Industry, Second Edition,
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steamsourcebook.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

3.6.6 Nomenclature

C_p – specific heat of air/water/process stream
E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
h_{cond} – enthalpy of condensate leaving the heat exchanger (saturated at flash/vent steam pressure)
h_{fw} – enthalpy of feedwater entering the boiler
h_{flash} – enthalpy of flash/vented steam (saturated at flash/vent steam pressure)
h_{steam} – enthalpy of steam generated by the boiler
m_{fluid} – mass flow rate of air/water/process stream
m_{fuel_saved} – saved fuel flow rate
m_{steam} – mass flow rate of steam saved
Q_{HX} – heat duty of the heat exchanger (thermal energy saved)
T_{in} – inlet temperature of air/water/process stream
T_{out} – outlet temperature of air/water/process stream
V_{fluid} – volume flow rate of air/water/process stream

Greek Symbols

η_{boiler} – boiler efficiency
ρ_{fluid} – density of air/water/process stream

3.7 STEAM ENERGY ASSESSMENT IMPROVEMENT OPPORTUNITY #7, IMPROVE CONDENSATE RECOVERY

3.7.1 Description

Condensate is produced after steam has transferred its thermal energy and condensed into water. There is a significant amount of thermal energy still associated with this condensate. Every unit of condensate recovered implies one less unit of makeup water required. Hence, returning additional condensate:

- Reduces the energy required to heat makeup water in the deaerator
- Reduces makeup water
- Reduces chemicals for water treatment
- Reduces quenching water needed for sewers
- May reduce blowdown

There are three major areas where condensate is produced and needs to be recovered in a steam system:

- End-use equipment
- Distribution (header) system
- Heat tracing system

Some processes and end uses utilize direct injection of steam into the process or water streams, and condensate cannot be recovered from those applications. Nevertheless, optimizing condensate recovery from end uses begins by evaluating the amount of condensate that can be returned. Condensate returned should also be evaluated on the basis of different pressure header levels. In large industrial plants with extensive steam distribution systems and multiple steam end uses, condensate recovery depends on the following factors:

- Contamination levels
- Cost of recovery equipment
- Cost of condensate piping

Commercial technology can now monitor in real time the contaminant levels in condensate . These technologies have been successfully implemented in many plants and facilities to aggressively collect condensate from all possible avenues, including those areas that may have a probability of contaminated condensate. Their functionality is based on monitoring a certain contaminant level or conductivity of condensate, and once those levels are exceeded, then a dump valve opens to sewer the condensate and simultaneously shuts off the return to the boiler plant. Every situation needs to be evaluated on its own merit and application. Sometimes it may not be cost effective to collect a small amount of condensate and take a high risk on contaminating the boiler feedwater system.

The cost of recovery equipment and piping will depend on the distance between the point of end use and the boiler plant, because the condensate would have to be piped to the boiler plant. Additionally, designs will have to consider electrically pumping condensate back versus using the steam pressure and a lift station.

Condensate receivers can serve as a local collection point and help to reduce project costs of individually pumping condensate back from each end user. Additionally, condensate receivers and flash tanks reduce the amount of steam entering the condensate return piping, and this mitigates flow restrictions in the return piping. It will also help to eliminate water hammer in condensate return systems. A schematic of this arrangement is presented in Fig. 8.

A steam distribution system can be extensive, with possibly miles of steam piping in an industrial plant. Even when the steam lines are well insulated, a certain amount of heat is lost, which leads to condensation in the steam headers, especially for saturated steam systems. In certain systems where carryover from the boilers is an issue, this problem is exacerbated and there is two-phase flow immediately from the generation area.

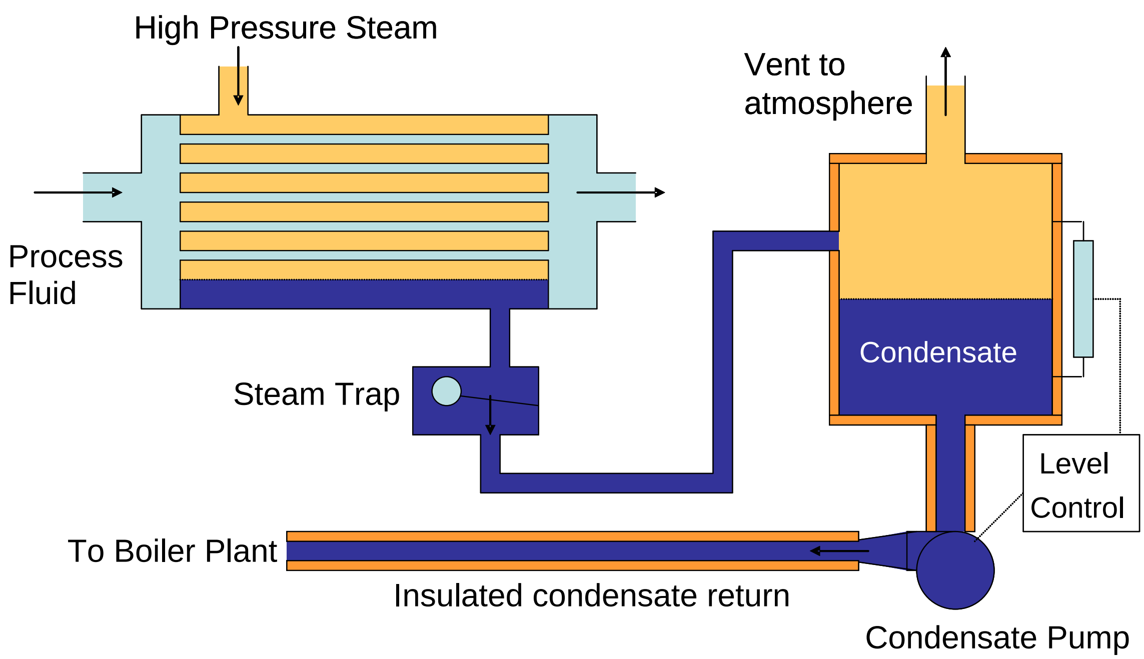

Fig. 8. Arrangement of condensate receiver and flash tank. (Courtesy: DOE ITP Steam BestPractices End User Training Program.)

Most industrial plants will have condensate (steam) traps to remove any and all condensate that forms in the steam header. Removal of condensate from the steam header ensures a highly reliable steam system operation and results in the following BestPractices:

- Steam header does not have excessive pressure drop
- No water hammer results in the steam header due to two-phase flow regime
- Process end use receives dry steam
- Major equipment such as turbines receive dry steam
- No corrosion, pitting, or erosion on pipe fittings, valves, etc.

Condensate that is drained from the steam headers can be flashed in a flash tank/separator vessel to a lower pressure steam header. The remainder of the condensate can either be sent back to the boiler plant directly or to a cascade condensate return system. Some industrial plants have excellent condensate removal from the steam headers but may not be returning condensate and instead may be dumping it. There is both an energy and economic loss to dumping condensate removed from the steam headers.

Most heat tracing systems using steam typically do not have a condensate return system and bleed all the condensate to grade. In some instances, instead of a steam trap, a valve is cracked “open” to continuously allow condensate to drain and a small amount of steam to leak. This is done principally to ensure that no condensate ever becomes backed up in the steam tracing lines, else their functionality will be impaired with a high risk on reliability of operations.

It is clear from the above discussions that higher condensate return temperatures imply less heating required in the deaerator. This directly translates to fuel energy savings. But collecting and returning high temperature condensate may need significant due-diligence which, if not provided, could result in operational problems. The biggest concern is the possibility of flashing occurring in the condensate return lines. The problem can be magnified in a cascade system, where condensate from different locations is mixed and there are large temperature differences between the condensate returns.

The steam system optimization strategy weighs the additional cost of dedicated high temperature condensate return compared to having a condensate receiver/flash tank (with an ambient vent) to remove this extra thermal energy. Depending on the amount of condensate, this thermal energy can be significant, and every effort should be made to capture condensate and return it to the boiler plant with the highest thermal energy possible.

3.7.2 Field Measurements Required

- Estimate of the flow rate of additional condensate to be returned to the boiler plant
- Condensate temperature at point of collection
- Condensate return temperature measured at boiler plant (or main condensate return tank)
- Boiler efficiency (combustion efficiency at a minimum)
- Makeup water temperature

3.7.3 Energy Savings Calculation Method

The fuel energy savings possible from improving condensate return are presented below. However, depending on the complexity of the steam system, use of a detailed steam system model, such as the DOE SSAT, can improve the accuracy of the prediction by including system considerations that might not be included in manual calculations.

The amount of condensate to be recovered can be obtained in several different ways, including:

- Steam flow rate to the end use
- Energy and mass balance on the process end-use heat exchanger
- Bucket and stopwatch (exercise extreme caution)
- Design conditions
- Steam trap size

If a volumetric measurement is available (such as from a bucket and stopwatch methodology), then the mass flow of condensate to be returned is calculated as follows:

$$m_{cond} = V_{cond} \times \rho_{cond}$$

where V_{cond} is the volume flow rate and ρ_{cond} is the density of condensate. The density of condensate can be obtained from steam tables using the condensate temperature and the atmospheric pressure.

The amount of thermal energy in the condensate compared to equivalent makeup water is calculated as follows:

$$Q_{cond} = m_{cond} \times \left(h_{cond} - h_{mu}\right)$$

where h_{cond} is the enthalpy of condensate at the boiler plant (or main condensate tank) and h_{mu} is the enthalpy of makeup water. These are obtained from steam tables.

In an industrial steam system, the makeup water would be heated by the steam in the deaerator. This implies that the actual fuel energy savings would need to incorporate the boiler inefficiencies. Hence, fuel energy savings and fuel savings for additional condensate returned in the steam system are calculated as follows:

$$E_{fuel\_saved} = \left(\frac{Q_{cond}}{\eta_{boiler}} \right)$$

$$m_{fuel\_saved} = \left(\frac{E_{fuel\_saved}}{HHV_{fuel}} \right)$$

3.7.4 Possible Exceptions to Realizing These Energy Savings

Although the total potential for these energy and fuel savings will be realized in most circumstances, there are exceptions to realizing these energy savings. These systems include:

- Processes that have direct injection of steam, so condensate *cannot* be collected
- Condensate is contaminated and needs a significant amount of treatment before returning it to the boiler plant
- Cogeneration systems that have back-pressure steam turbine operations
- Multipressure complex condensate recovery, which may involve flash steam recovery, etc.

Typical energy savings from this opportunity: 1.0–3.0% of an individual facility's annual steam system fuel energy use

Typical payback for implementing this opportunity: 1–2 years

3.7.5 Key References

DOE Steam Tip, "Return Condensate to Boiler," http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam8_boiler.pdf

Steam System Survey Guide, http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam_survey_guide.pdf

Save Energy Now Assessment Summary Reports, 2006, 2007, 2008

Industrial Assessment Centers Database, http://iac.rutgers.edu/database

3.7.6 Nomenclature

E_{fuel_saved} – fuel energy saved
HHV_{fuel} – higher heating value of fuel
H_{cond} – enthalpy of condensate
h_{mu} – enthalpy of makeup water
m_{cond} – mass flow rate of additional condensate to be returned
m_{fuel_saved} – saved fuel flow rate
Q_{cond} – thermal energy recovery

Greek Symbol

η_{boiler} – boiler efficiency

4. DOCUMENTING SAVINGS AND RESULTING CREDITS

Section 63.7533 of the Boiler MACT rule outlines the major requirements for utilizing energy conservation measures identified from energy assessments to determine emission credits. These requirements can be summarized as follows.

- Establish a baseline from which emissions reductions may be generated by determining the actual fuel input to the affected boiler before initiation of the energy savings measures.

- Calculate and document the emission credits due to energy savings measures for the affected boilers.

- Develop and submit an implementation plan for all boilers included in applying emissions credits. The plan shall include a description of the energy conservation measures implemented and the energy savings generated from each measure, and an explanation of the criteria used for determining savings.

- Comply with General Reporting Requirements.

- Apply the emission credits as outlined in Section 63.7533.

This section provides some additional discussion and details about establishing a baseline and documenting energy savings and the resulting energy credits.

4.1 ESTABLISHING A BASELINE

It is necessary to document energy use to establish an energy use baseline against which energy efficiency improvements can be applied. Three types of energy use need to be documented for the calculation of emission credits from energy conservation measures:

- **Energy use for the "affected boiler."** The annual fuel energy use of each affected boiler for which emission credits will be applied needs to be determined and documented. This energy use is to be reported in TBtu/year heat input to the boiler. The baseline shall be based on using the most representative, accurate, and reliable process available. The baseline shall be established for a one-year period prior to the date that an energy savings occurs, unless it can be demonstrated that a different time period is more representative of historical operations.

  Some of the steam systems that are impacted by the Boiler MACT Rule may have only one boiler. For steam systems that have multiple boilers, there may be one or multiple "affected boilers" in the system, and the energy use for these boilers must be documented.

  Also, an affected boiler may use multiple fuels; therefore, all of the fuels used for the affected boiler would need to be included in determining the total TBtu/year heat input for that boiler.

- **Inventory of all fuels purchased and generated on-site.** An inventory must be created of all fuels purchased and generated on-site, such as off-gases and residues, and report energy use for these fuels in physical units (i.e., MMBtu, million cubic feet, etc.).

- **Energy uses from the affected boiler.** All uses of energy from the affected boiler are to be documented by use of the most recent data available.

- **Documenting non-energy data.** Non-energy-related facility and operational data must be collected and documented to normalize, if necessary, the baseline to current operations. Such data could include building size, operating hours, weather, production levels, etc. If possible, actual data that are current and timely should be used rather than estimated data.

4.2 DOCUMENTING ENERGY SAVINGS

The following is a process for documenting energy savings in order to claim emissions credits from steam system improvements. Figure 9 shows the elements of this process, which are described below.

- **Step 1. Estimate savings from potential energy savings opportunities.** Energy savings estimates for improvements (e.g., in steam systems, reducing boiler blowdown) are typically made by modeling. Steam system models can be of three types: a) hand calculations based on sound engineering principles, b) simple steam calculation models developed by steam system analysts, or c) more complex steam system models that accommodate interactions between steam system components.

  Regardless of the methodology employed, it is important to note that calculations must be based on accepted engineering principles and adhere to the fundamental laws of thermodynamics. This also applies to any software tool used for estimating savings.

  For many steam systems, hand calculations or simple calculation models can provide sufficient accuracy for the savings estimates. For some systems, however, particularly steam systems that include backpressure turbines, more complex steam-system-based models need to be used to obtain valid savings estimates.

  The type of modeling used should be documented in the implementation plan, including an explanation of why this modeling approach is appropriate for the affected facility.

- **Step 2. Identify equipment needs and modifications for the proposed savings opportunity, and implement the opportunity.** In this phase the identified savings opportunity will actually be implemented. The facility will need to go through a process for determining what equipment modifications and/or facility operational changes need to be achieved to implement the opportunity and put these modifications in place.

  The implementation plan should include a brief discussion of the actual facility modifications or operational changes needed to implement each assessment savings opportunity.

- **Step 3. When equipment is installed or operations modified, ensure that modifications are operating as expected, then verify savings estimates.** Once facility modifications are in place to implement an energy savings measure, the first step toward verification of energy savings is to ensure that the modifications are operating as expected. Then, there are three possible paths to the final verification of energy savings estimates:

  1. In some facilities utility metering systems may be available, and metering results can be analyzed to verify energy savings from the adjusted baseline data.

  2. If the facility modifications operate as expected (i.e., key operating conditions such as temperature, pressures, and flow rate changes can be quantified and reasonably agree with the values predicted in the models), then it is reasonable to expect that the resultant savings will be

those obtained from the analyses performed in Step 1. This is the typical way that savings verification is performed in facilities where metering is unavailable;

3. If the facility modifications do not operate as expected, it would then be necessary for the Step 1 analyses to be redone to determine the expected "as is" savings that result from implementation of the improvement project.

The implementation plan should include documentation of how the equipment modifications actually operated and details on which of the three paths were used for verifying the final project savings.

- **Step 4. Document savings estimates, equipment operation, and final savings verification.** This step will actually be complete if the facility provides the documentation recommended in Steps 1 through 3.

4.2.1 Tools for Reporting/Tracking Savings

The DOE Technology Deployment initiative has two software tools useful for developing facility energy baselines and evaluating and estimating steam system energy system improvements:

Plant Energy Profiler (ePEP). The Plant Energy Profiler, or ePEP (formerly Quick PEP) is a free online software tool to help U.S. industrial plant managers improve energy management at industrial facilities. The tool helps users establish a baseline for how energy is being used at their plant, and identify best opportunities to save energy and money, and calculate emissions. With ePEP, a user can complete a plant profile in about an hour.

http://www1.eere.energy.gov/industry/bestpractices/software_quickpep.html

Steam System Assessment Tool (SSAT). The SSAT allows steam analysts to develop approximate models of real steam systems. Using these models, they can apply SSAT to quantify the magnitude—energy, cost, and emissions savings—of key potential steam improvement opportunities. SSAT contains the key features of typical steam systems.

http://www1.eere.energy.gov/industry/bestpractices/software_ssat.html

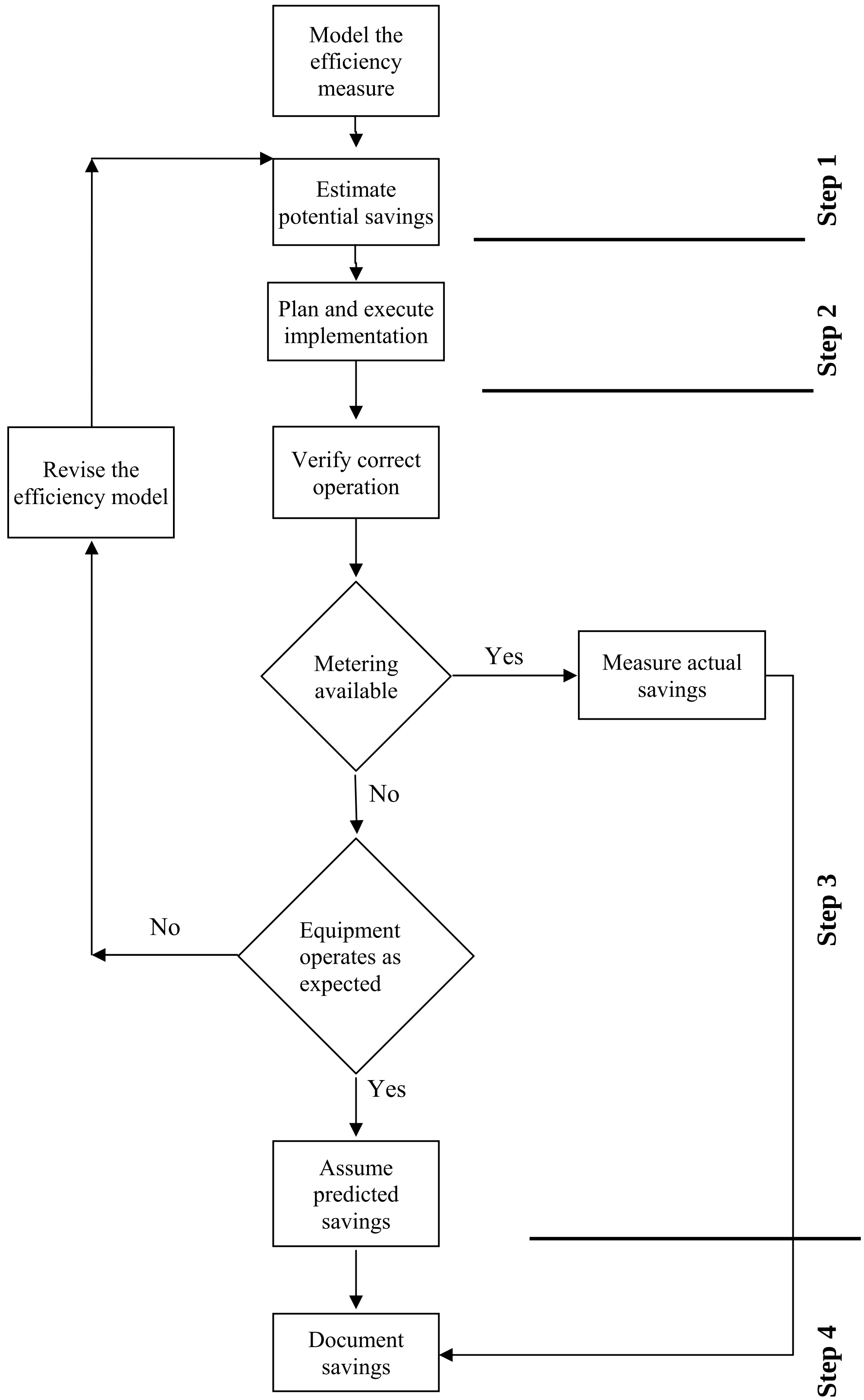

Fig. 9. Elements of energy assessment verification.

5. AVAILABLE RESOURCES FOR FURTHER INFORMATION

The DOE EERE Advanced Manufacturing Office (AMO) Technology Deployment initiative has developed, in partnership with U.S. industry and service providers, a large group of valuable documents, software tools, and training that can assist facilities in conducting effective steam system energy assessments. These resources are described in this section, including web links to the available materials.

5.1 DOCUMENTS

Steam System Sourcebook. This document provides an overview of steam system basics, typical performance improvement opportunities in steam systems, and important references (both from DOE and from industry) to assist facilities in improving their steam use.

http://www1.eere.energy.gov/industry/bestpractices/pdfs/steamsourcebook.pdf

Steam System Survey Guide. The Steam System Survey Guide provides technical information for steam system operational personnel and plant energy managers on some of the major opportunities available to improve the energy efficiency and productivity of industrial steam systems. Much of the information in the Survey Guide is also relevant to steam improvement opportunities in commercial and institutional steam systems.

http://www1.eere.energy.gov/industry/bestpractices/pdfs/steam_survey_guide.pdf

Steam Tip Sheets. These two-page tip sheets give engineers, technicians, equipment operators, and others technical advice to improve steam systems. There are 26 available steam tip sheets on a range of potential steam improvement opportunities.

http://www1.eere.energy.gov/industry/bestpractices/tip_sheets_steam.html

ASME Steam System Assessment Standard and Guidance Documents. This ASME Standard sets the requirements for conducting and reporting the results of a steam system energy assessment (hereafter referenced as an assessment) that considers the entire system, from energy inputs to the work performed as the result of these inputs. This Standard is designed to be applied primarily at industrial facilities, but most of the specified procedures can be used in other facilities such as those in the institutional and commercial sectors. The guidance document discusses specific elements of how to implement the Standard.

http://www.asme.org/products/codes---standards/energy-assessment-for-steam-systems

Recommendations from Completed Assessments. Recommendations from completed assessments may be searched to identify additional opportunities to implement conservation measures.

http://www1.eere.energy.gov/manufacturing/tech_deployment/assessment_recommendations.html

5.2 STEAM SOFTWARE TOOLS

The DOE Technology Deployment initiative offers a collection of three software tools designed to help facilities identify, analyze, and quantify steam system energy efficiency savings. These tools are the Steam System Scoping Tool (SSST), the Steam System Assessment Tool (SSAT), and the 3E-Plus Insulation Appraisal software (developed by the North American Insulation Manufacturer’s Association). All of these software tools are freely available to the public.

http://www1.eere.energy.gov/industry/bestpractices/steam.html

Steam system analysis and evaluation software tools are also available commercially. Any software tool utilized must employ methodologies and algorithms based on accepted engineering practices and the fundamental laws of thermodynamics.

5.3 STEAM SYSTEM TRAINING

DOE steam training. Under the DOE Technology Deployment initiative, three types of steam training are available to the public:

- A one-day Steam End Use Training Workshop, which covers the operation of typical steam systems and discusses methods of system efficiency improvement
- A Web-based version of the one-day Steam End Use Training Workshop
- A Steam System Specialist Qualification, a 2½-day workshop for steam service providers and steam end users who are interested in becoming proficient in using the DOE steam software tools

While primarily designed for industrial applications, many of the principles from this training are relevant to commercial and institutional facilities.

http://www1.eere.energy.gov/industry/bestpractices/steam_systems.html

Industry-sponsored steam system training. Many U.S. steam service providers have developed and offer their own steam system improvement training; steam facility personnel can contact their service providers to determine training opportunities.

APPENDIX A.
ENERGY SAVINGS ASSESSMENTS

APPENDIX A. ENERGY SAVINGS ASSESSMENTS

Table A-1. Typical opportunities identified during Save Energy NOW (SEN) energy savings assessments for plants that consume approximately 0.3 TBtu/yr (Source)

Steam Opportunity Description	Average Source Energy Consumption (MMBtu/yr)	Average of Total Source Energy Savings (MMBtu/yr)	Average % of Energy Bill Projected to be Saved (%)	Average of Payback (Years)
Feedwater Heat Recovery – General	294,100	4,300	1.7	1.61
Reduce or Recover Vented Steam	367,400	5,000	1.6	0.83
Implement Steam Trap Maintenance Program	324,000	2,700	1.2	0.85
Change Condensate Recovery Rates	328,900	2,100	0.8	2.01
Improve Insulation	345,400	1,900	0.8	1.06
Implement Steam Leak Maintenance Program	279,200	800	0.4	0.92
Recover Heat from Boiler Blowdown	315,700	1,300	0.6	1.63

Table A-2. Typical opportunities identified during Industrial Assessment Center (IAC) energy savings assessments for plants that consume less than 0.3 TBtu/yr (Source)

Steam Opportunity Description	Average Source Energy Consumption (MMBtu/yr)	Average of Total Source Energy Savings (MMBtu/yr)	Average % of Energy Bill Projected to be Saved (%)	Average of Payback (Years)
Insulate steam / hot water lines	145,000	1,100	1.2%	1.2
	144,000	2,700	2.1%	1.9
Repair or replace steam traps	185,000	3,800	2.5%	0.4
Repair and eliminate steam leaks	169,000	4,800	3.8%	0.2
Repair leaks in lines and valves	132,000	1,300	1.3%	0.3
Increase amount of condensate returned	174,000	2,700	1.9%	1.3
Recover heat from boiler blowdown	206,000	2,400	1.3%	2.1
Recover heat from exhausted steam	196,000	5,300	2.6%	0.9
Use minimum steam operating pressure	163,000	1,800	0.9%	0.2
Insulate feedwater tank	125,000	500	0.7%	0.7
Install / repair insulation on condensate lines	175,000	6,200	4.1%	1.3

Table A-3. Typical opportunities identified during energy savings assessments for plants that consume between 0.3 and 1.0 TBtu/yr (Source)

Steam Opportunity Description	Average Source Energy Consumption (MMBtu/yr)	Average of Total Source Energy Savings (MMBtu/yr)	Average % of Energy Bill Projected to be Saved (%)	Average of Payback (Years)
Implement Steam Trap Maintenance Program	1,001,000	6,700	0.7	0.76
Change Condensate Recovery Rates	1,071,000	6,600	0.7	1.56
Improve Insulation	945,000	4,800	0.6	1.09
Implement Steam Leak Maintenance Program	916,000	2,600	0.3	0.61
Change Boiler Blowdown Rate	1,043,000	3,200	0.3	1.81

Table A-4. Typical opportunities identified during energy savings assessments for plants that consume greater than 1.0 TBtu/yr (Source)

Steam Opportunity Description	Average Source Energy Consumption (MMBtu/yr)	Average of Total Source Energy Savings (MMBtu/yr)	Average % of Energy Bill Projected to be Saved (%)	Average of Payback (Years)
Feedwater Heat Recovery - General	5,507,000	68,000	1.0	1.21
Change Condensate Recovery Rates	11,285,000	43,000	0.6	1.24
Modify Low Pressure Condensate Flash System	13,750,000	33,000	0.5	1.32
Install Blowdown Flash to Low Pressure Steam	34,002,000	28,000	0.5	0.87
Implement Steam Trap Maintenance Program	11,454,000	32,000	0.4	0.59
Reduce or Recover Vented Steam	17,935,000	29,000	0.4	0.81
Change Boiler Blowdown Rate	17,755,000	28,000	0.3	1.72
Recover Heat from Boiler Blowdown	11,259,000	27,000	0.3	1.02
Implement Steam Leak Maintenance Program	16,463,000	20,000	0.3	0.87
Improve Insulation	13,903,000	20,000	0.3	1.04

Concept for an Energy Assessment Energy Credit Form

(Shown with one opportunity. Can be duplicated as necessary)

LINE	FACILITY INFORMATION	DATA COLUMN	COMMENTS
1			
2	Name of Facility		
3	Location of Facility		
4	Type of Facility		
5	Facility Contact Person Information		
6			
7	Number of Affected Boilers in Facility		
8	Date When Energy Assessment Performed		
9			
10	Start Date for Measuring Progress		
11			
12			
	FOR EACH FACILITY AFFECTED BOILER:		
14			
15	Name/Description of Facility Affected Boiler		
16	Boiler Output Rating	MMBtu/hr?	
17			
18	Start Date for Energy Baseline for Affected Boiler	date…	1 year before time energy reduction occurs, unless different time period more representative.
19	Initial Energy Input Baseline for the Affected Boiler	MMBtu/year	This is baseline without normalizing….
20			
21	Are you Normalizing Affected Boiler Energy Baseline?	Yes/No	
23	If YES, Describe How Normalizing Baseline (briefly)	Description of How Normalize Baseline	
25	**Final Energy Input Baseline for Affected Boiler**	MMBtu/year	
27	Date Energy Assessment Performed	date…	
28	Total Number of Energy Credits	#	
	SUMMARY ENERGY CREDIT DATA		
33	**Final Energy Input Baseline for Affected Boiler**	MMBtu/year	Same as line 25 above.

Concept for an Energy Assessment Energy Credit Form

(Shown with one opportunity. Can be duplicated as necessary)

LINE	FACILITY INFORMATION	DATA COLUMN	COMMENTS
35	**SUM of Energy Savings for All Verified Energy Savings Opportunities**	MMBtu/year	This will be the calculated sum of all of the energy savings users enter below
37	**TOTAL Energy Credits**	Expressed as a decimal fraction of the baseline energy input	This will be a calculation of line 35 divided by line 33
	COMPLETE FOR EACH ENERGY CREDIT OPPORTUNITY		
	Energy Credit Opportunity #1		
	Brief description of energy savings opportunity	Description (short)	
43	How Energy Savings Opportunity Estimated	Type of model used?	Maybe have drop down menu for different types of models - hand calculation, spreadsheet, system model?
44	ESTIMATED Energy Savings for Opportunity	MMBtu/year	
45	Estimated Payback for Savings Opportunity	Payback (years)	
47	Brief Description of Facility Modifications Needed to Implement Opportunity	Facility mod description	
48	Anticipated date when savings opportunity will be implemented	date….	
50	Describe Criteria for Verifying Energy Savings	1. - IF MEASUREMENT, DESCRIBE HOW MEASUREMENTS MADE TO VERIFY	
51		2. - IF NOT MEASUREMENT, DESCRIBE HOW ENSURING EQUIPMENT INSTALLED TO LEAD TO SAVINGS	
	Final VERIFIED Energy Savings for Opportunity	MMBtu/year	

Boiler Tune-up Guide; National Emission Standards for Hazardous Air Pollutants for Area Sources: Industrial, Commercial, and Institutional Boilers; 40 CFR Part 63 Subpart JJJJJJ [1] , http://www.epa.gov/ttn/atw/boiler/boilerpg.html